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THE GYPSY AND BROWN-TAIL MOTHS AND THEIR CONTROL[1]

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THE GYPSY MOTH

HISTORY OF THE PEST IN THE UNITED STATES

In 1869 a number of egg clusters of the gypsy moth (*Porthetria dispar* L.) were brought from France to Medford, Mass., by a French mathematician and astronomer, who had the idea that he could cross this insect with silkworm moths and thus develop a hardy race of silk-producing insects. In the course of his rearing experiments some of the eggs were accidentally lost or some of the caterpillars escaped, and he made at that time public acknowledgment of this fact, evidently appreciating the danger.

The insect increased slowly at first. After 10 years it seemed to have been noticed by local residents but was believed to be some native caterpillar. Not until the summer of 1889, or 20 years after its introduction, did this insect become so abundant and destructive as to bring it into general public notice. At that time fruit and shade trees were completely defoliated, and the caterpillars, swarming

[1] This circular supersedes Farmers' Bulletin 1623, The Gipsy Moth and the Brown-Tail Moth.

into the houses, became a very grave nuisance. The situation was so serious that the State of Massachusetts appropriated funds and delegated to the State Department of Agriculture the task of exterminating this pest.

The infested area then covered about 359 square miles, and trees in many towns around Boston were completely defoliated each season for a number of years. As the work continued, more effective methods of treatment were developed and better results were obtained; consequently, during the summers of 1898 and 1899 little defoliation could be found in the entire area and few specimens of the moth were located throughout the residential sections. Careful examination indicated that the insect had been exterminated in some of the towns bordering the originally infested area. In February 1900 the legislature ordered the work discontinued because of the popular belief that the danger had passed, in spite of the advice of experts that the insect had not been stamped out.

During the next 5 years the insect increased enormously. Many of the towns and cities in the old infested area were overrun with caterpillars, which completely defoliated trees in many of the residential sections, and thousands of acres of woodland were stripped of leaves during the summer. The situation became so serious and intolerable that in 1905 the State resumed control work. In the meantime the insect had spread far beyond the original limits of infestation, more than 2,224 square miles being involved in Massachusetts as well as many isolated areas in Maine, New Hampshire, and Rhode Island.

In 1906 an appropriation was made by Congress, and the Secretary of Agriculture was authorized to take all possible measures, in cooperation with the States concerned, to prevent the spread of this pest. The insect had increased to such enormous numbers and had spread so rapidly that the utmost efforts of the Federal and State forces were only able to apply relief measures in the badly infested residential sections and slightly retard the continued spread of the pest. Efforts were made to prevent the shipment of the insect to uninfested localities by inspecting products that were likely to carry it. This phase of the work was greatly strengthened as a result of the enactment of the plant quarantine law by Congress on August 20, 1912. Since October of that year shipments from the infested district have been regulated by Federal quarantine.

On account of the continued spread and increasing damage caused by this insect, efforts were constantly being made to develop better means of control. The process of manufacturing lead arsenate, which was first made and used on the gypsy moth work in 1893, was improved so that the cost of production was reduced and the product could be more effectively applied. Spraying machinery and equipment were developed to a high point of efficiency. The details of field management were constantly improved, following experimental work in carrying on field operations, in order that the greatest possible volume of effective work could be done with the funds available.

In spite of the efforts that were made by the Federal Government and all the States concerned, the insect continued to spread. By 1914 it had covered the southern half of New Hampshire and extended as far east as Bangor, Maine. On the west it had crossed the Connecticut River in Massachusetts and into Vermont. Rhode Island and towns in eastern Connecticut were found to be infested.

During the war period conditions were unfavorable for preventing spread. The loss of efficient personnel and the constant turn-over of men, together with extraordinary increase in costs, made progress difficult. By the fall of 1922 scattered colonies were found farther west in Vermont, Massachusetts, and Connecticut, and in New York State near the Massachusetts State line. There was every indication of the continued spread of the insect unless more intensive work was done.

To meet this serious situation a conference was held in the office of the commissioner of farms and markets in Albany, November 26, 1922, which was attended by representatives from all the infested States, the Dominion of Canada, and the United States Department of Agriculture.[2] The entire subject of the prevention of spread of the gypsy moth and its control was discussed, and a resolution was adopted urging that sufficient funds be obtained from the States interested and the Federal Government to continue and strengthen control methods in the infested area, to do necessary scouting for the discovery and destruction of border infestations, to determine the location of the most practical place for a control zone, to take necessary steps to make control therein effective, and to destroy all infestations in and west of said zone.

To carry out this project, in April 1923 the State of New York appropriated $150,000 to be administered by the Department of Conservation. Federal funds were also provided for the fiscal year beginning July 1, 1923, to bring about effective cooperation.

The plan finally adopted, by the Federal and State authorities, was to locate a zone where clean-up operations to prevent westward spread of this pest would be centered. This barrier zone embraced an area of about 9,000 square miles east of the Hudson River extending from Long Island Sound (excluding Westchester County, N. Y.) to the Canadian border, a distance of more than 250 miles, and ranging in width from 25 to 30 miles (fig. 1). This is the shortest and most feasible area in the United States that could be selected to prevent Nation-wide spread of the insect. The territory east of this zone was to be treated by the States concerned as far as their funds would permit, and their work was to be supplemented by liberation of imported parasites and other natural enemies of the insect by the Bureau of Entomology. Work in the New York portion of the area was to be financed by the State, with such assistance as could be given by the Bureau after covering the eastern part of the zone in western Vermont, Massachusetts, and Connecticut.

While much of the extremely rugged country in the Adirondacks in northern New York and the Green Mountains in Vermont was avoided, as well as the Catskills and some of the rougher country west of the Connecticut River in Connecticut, there are areas in this zone, embracing the Berkshire Hills in western Massachusetts and some of the territory directly south and southwest of them in Connecticut and New York, where the terrain is extremely difficult.

In 1924, owing to the number of infestations found in Massachusetts and Vermont, and the discovery of a colony at Henrysburg, Quebec, by the inspection force of the Dominion entomologist of Canada, the quarantine line was moved westward from the eastern

[2] FELT, E. P., and others. THE GYPSY MOTH, AN IMMINENT MENACE TO THE FOREST AND SHADE TREES OF THE STATE OF NEW YORK. N. Y. State Dept. Farms and Markets Agr. Bull. 148, 58 pp., illus. 1922.

boundary of the zone to embrace the entire State of Vermont and additional towns in northwestern Connecticut. A foreign quarantine regulating the movement of Christmas trees was made effective covering the southern tier of towns in the Province of Quebec. In 1926, owing to the effectiveness of the clean-up work in the zone and the fact that scouting west of the zone showed no infestation, the area under quarantine lying in the zone was eliminated from quarantine. The Canadian quarantine was withdrawn July 1, 1928.

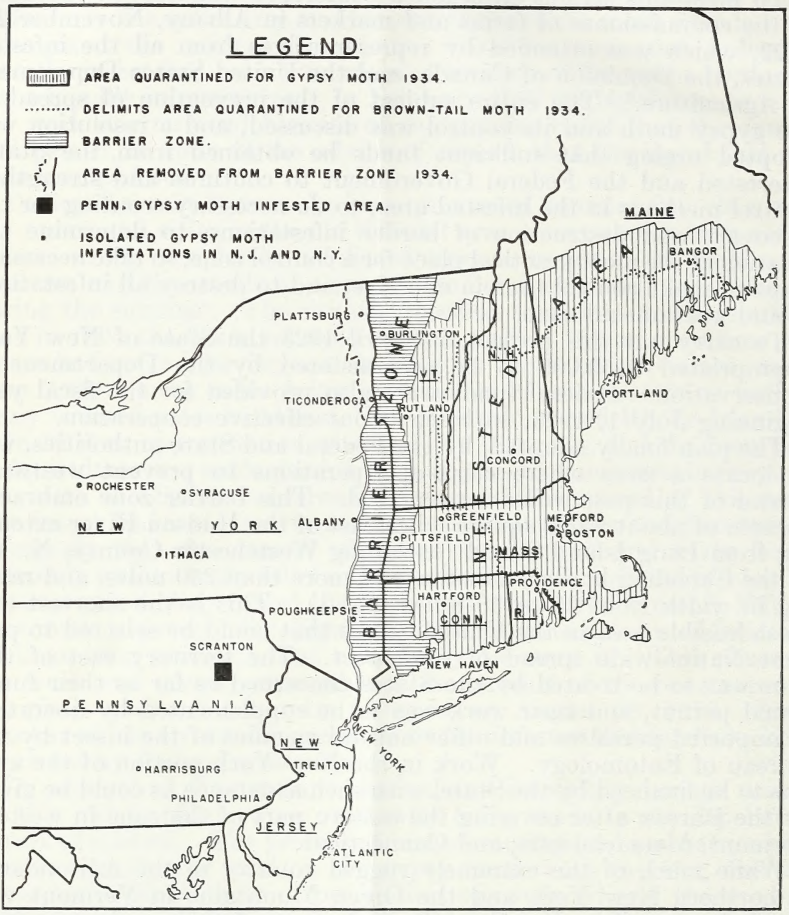

FIGURE 1.—Barrier zone and status of the gypsy moth and brown-tail moth control areas at the end of 1934.

Later in 1928 more infestations were found in the Massachusetts and northern Connecticut portions of the barrier zone than during the previous fiscal year. This made the problem far more difficult and emphasized the necessity of carrying on work in the territory east of the zone to facilitate eradication in the zone itself. Since there was also an increase in infestation directly east of the zone, 7 towns in Vermont, 12 in Massachusetts, and 31 in Connecticut, embracing an area of 1,581 square miles, were reclassified from the lightly infested to the generally infested area.

Scouting during the latter half of 1929 and the first half of 1930 showed a further increase in the number of infestations in the barrier zone, and Congress made additional funds available for clean-up work. No provision was made, however, for examination of territory immediately east of the zone to check the increase there. The infestations located in 1929 and 1930 were new ones, as most of those previously discovered had been cleaned up.

In 1933, after the passage of the National Industrial Recovery Act, funds were made available and extensive scouting and clean-up work was undertaken between the barrier zone and the Connecticut River. This was extended very materially by personnel from certain Civilian Conservation Corps camps, which were supervised by the gypsy moth organization of the Bureau of Entomology and Plant Quarantine through cooperative arrangements with the Forest Service of the United States Department of Agriculture, the State forest services, and the United States Department of the Interior.

The prompt elimination of a few sporadic colonies that had been found just beyond the zone, together with the suitability of the area in the zone for effective clean-up, offers conclusive proof of the feasibility of checking westward spread.

In 1934 a change in quarantine was made by transferring from the lightly to the generally infested area 74 towns in Maine, 5 in New Hampshire, 2 in Vermont, and 3 in Connecticut. In northern Vermont 39 towns were dropped from quarantine. The barrier zone line in northeastern New York was relocated on the New York-Vermont State line, thus eliminating 807 square miles, and a strip of towns in Vermont adjoining the barrier zone on the east, aggregating 604 square miles, was added to the zone.

Since July 1935 emergency funds have been made available for gypsy moth work, and more scouting and clean-up work has been carried on than heretofore. This has suppressed the insect in many isolated colonies and improved the condition in the barrier zone and the area adjoining it to the east.

CONDITIONS OF INFESTATION IN NEW ENGLAND

From the beginning of its gypsy moth work the Bureau of Entomology obtained general records of the density of local and general infestations in the territory not covered by the Bureau. Since 1911, however, counts of egg clusters have been taken annually from a series of woodland plots in the eastern portion of the infested area. They are summarized as follows:

Year	*Egg clusters per acre*	Year	*Egg clusters per acre*
1911	5, 214	1923	110
1912	5, 407	1924	50
1913	2, 635	1925	61
1914	3, 658	1926	127
1915	4, 400	1927	303
1916	3, 751	1928	722
1917	3, 702	1929	407
1918	2, 273	1930	66
1919	4, 032	1931	42
1920	2, 134	1932	112
1921	2, 387	1933	344
1922	402	1934	181

As the habits and the variable mortality of the gypsy moth and its food-plant limitations cause wide differences in its abundance in various parts of the infested area, it has seemed that the damage done and the possibilities of greatest future injury could be gaged most accurately by determining the defoliation caused by the species over the area as a whole. The total acreage showing from 25- to 100-percent defoliation each year beginning in 1924, when defoliation was less than in any previous year, is as follows:

Year	*Acres defoliated*	Year	*Acres defoliated*
1924	825	1931	204, 720
1925	48, 560	1932	286, 395
1926	80, 822	1933	397, 730
1927	140, 920	1934	492, 361
1928	262, 514	1935	540, 769
1929	551, 133	1936	428, 622
1930	288, 225		

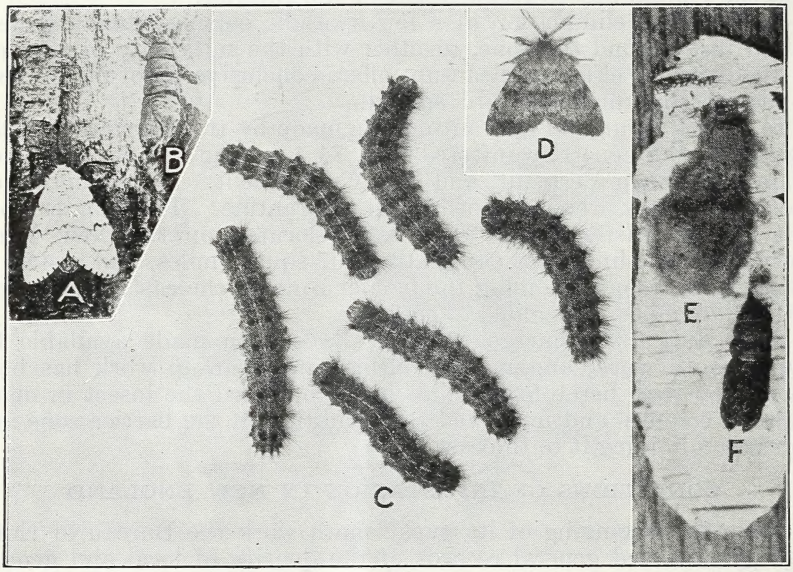

FIGURE 2.—Life stages of the gypsy moth: *A*, Female moth; *B* and *F*, pupae; *C*, larvae or caterpillars; *D*, male moth; *E*, egg mass. All about three-fourths natural size.

The danger of reinfestation of the barrier zone depends largely on the severity of infestation east of the zone. In the last 3 years the areas of defoliation were smaller in eastern Massachusetts and certain sections of southeastern New Hampshire, which comprise most of the older infested territory. In the same years heavy defoliation was noted much farther west in Massachusetts, and in 1934 and 1935 extensive areas of complete defoliation occurred in the Connecticut River Valley and the adjoining territory about 20 miles from the zone.

LIFE HISTORY

The gypsy moth passes through four stages—the egg, the larva or caterpillar, the pupa, and the adult or moth (fig. 2). There is one generation a year. The times of the year when the different forms may be found in the field are shown in figure 3.

THE EGGS

The female gypsy moth lays from 100 to 800 eggs in a cluster, depending on her size. The average number per cluster is approximately 400. In light infestations where the food supply is plentiful clusters are larger than the average, and in heavy infestations where the food supply becomes limited during the late larval stages they are smaller. Each cluster is covered with buff-colored hairs from the body of the female, which no doubt serve as a protection for the eggs during the long interval between oviposition and hatching.

Most of the egg clusters are laid in July and hatch the following spring. The hatching date varies from about May 1 in southern New England to May 25 in the extreme northern part. The date of oviposition bears no relation to the date of hatching, as eggs laid in mid-August may hatch at the same time as those laid early in July under the same environmental conditions. Eggs deposited in warm locations, as on the southern exposure of buildings, may hatch several days earlier than others laid in cool and moist locations.

The gypsy moth egg must be exposed to a chilling temperature before it will hatch. Just what this temperature is is unknown. Eggs that have undergone this conditioning process will hatch in midwinter in a warm building.

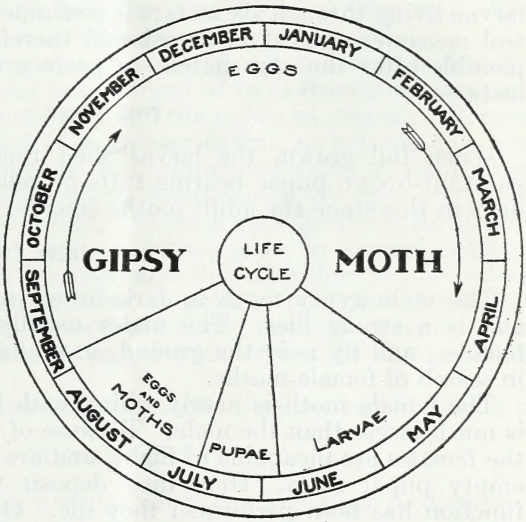

FIGURE 3.—Times of the year when the different stages of the gypsy moth are present in the field.

The female moth deposits her egg clusters on the trunks of trees, on the underside of limbs, under loose bark, in cavities in the trunks or branches, and sometimes on leaves, on ground debris, under stones, and in stone walls. When infested trees are found along stone walls, a large proportion of the eggs are often laid in the wall; but where the ground is free of stones or debris, a large proportion of clusters will be found on the tree trunks.

THE LARVAE

The newly hatched larvae begin immediately to search for palatable food. In pure stands of favored food this is a simple matter, but as the proportion of favored food in the stand decreases the problem becomes more acute. There is no evidence that such larvae can pick out a favored tree from an unfavored one without examining the foliage. They find the food through random movement. The normal mortality of first-stage larvae is very high. Newly hatched larvae can ordinarily live only about a week without feeding. The

absence of water becomes less of a problem as the larvae increase in size, probably because of the decrease in the ratio between evaporative surface and body volume.

First-instar larvae move very slowly. They are active only when the temperature is above 60° F. and are more active when the temperature is 70° or higher.

Gypsy moth larvae that are to become male moths molt five times, and those that are to be females molt six times. The full-grown larva is from 1½ to 2½ inches long. The head has yellow markings; the body is dusky or sooty colored, hairy, and on the dorsum is a double row of five pairs of blue spots followed by a double row of six pairs of red spots. As the larvae grow, the quantity of foliage eaten per day increases tremendously. Approximately 75 percent of all the foliage eaten by larvae having five instars is eaten in the fifth or last instar, and approximately 65 percent of the foliage eaten by larvae living through six instars is consumed in the last instar. Control measures against larvae should therefore be applied as soon as possible after the eggs hatch, to protect the foliage from the later instars.

THE PUPAE

When full grown, the larvae shed their skins and transform to chestnut-brown pupae bearing tufts of yellow hairs. After about 10 days in this stage the adult moths emerge.

THE ADULTS

The male gypsy moth is dark brown with black wing markings, and is a strong flier. The males usually emerge earlier than the females, and fly near the ground, in a characteristic zigzag manner, in search of female moths.

The female moth is nearly white, with black wing markings, and is much larger than the male. Because of the weight of their bodies, the females are incapable of flight, and are usually found beside their empty pupal cases. Here they deposit their eggs, and once this function has been performed they die. Oviposition begins within a day or two after the female emerges from the pupa. The moths do not feed.

INJURY CAUSED BY THE GYPSY MOTH

It is impossible to state with precision the loss to New England forests due to the ravages of the gypsy moth. The best information compiled from data extending over a long period of years indicates losses of many millions of dollars in tree growth. These losses have been due not only to the direct or indirect killing of the trees but also to the retardation of growth through defoliation. Although far less spectacular than the immediate killing of trees, the second type of loss is more to be feared, for tens of thousands of trees are so affected for every one killed. Most conifers, notably hemlock and white pine, are killed by a single complete defoliation. Most rapid-growing deciduous trees put out a new crop of foliage the same season in which stripping occurs; they are therefore without foliage but a

short interval during the growing season, but retardation of growth and less wood result.

Trees that are weakened by defoliation are susceptible to secondary injuries by fungi and bark borers. From 1912 to 1915 heavy mortality was noted among oaks that had been defoliated by the gypsy moth, and this was followed by an outbreak of the two-lined chestnut borer (*Agrilus bilineatus* Weber), whose larvae fed beneath the bark of the weakened trees. During recent years this beetle has not caused noticeable damage, but such a condition might recur without warning.

The importance of tree growth in aiding retention of moisture in the soil and preventing erosion, particularly in rugged country, is well recognized. Defoliation encourages evaporation of moisture from the soil during the most critical growing period in the summer, renders such areas more susceptible to forest fires, and undoubtedly diminishes the flow of small streams, some of which furnish the water supply for reservoirs maintained for commercial or city use. The money value of these losses cannot be readily computed.

Defoliated or dying trees along roadsides and streets in residential areas are objectionable, and the removal of trees from such locations is a distinct loss to the community and the public in general. Recreational areas are being used to a greater extent each year, and here the value of trees far outweighs the commercial value of the timber. Ragged foliage and denuded trees, accompanied by crawling caterpillars, are avoided by the public. Trees in such locations have more of a struggle for existence than trees that grow in natural environment without interference by man, and they therefore require added protection. The increased interest in natural playground development in New England and New York State seems to warrant more than ordinary expenditures to preserve the trees for their esthetic value alone.

Figures 4, 5, and 6 illustrate the results of gypsy moth feeding in various types of stands.

FOOD PLANTS

Unlike many leaf-eating insects, which confine their feeding to a single species or group of plants, the gypsy moth is a general feeder on trees and shrubs. In fact, in heavy infestations few species of trees are ignored, especially by the larger larvae, and when food is scarce grass and cultivated crops are sometimes eaten.

A study of the food plants of the gypsy moth in 1913 [3] revealed distinct differences in the preferences of the very small and the larger larvae. The food plants were grouped in four classes, which are given herewith, with a few changes that subsequent observations have justified. This classification can be used as a basis for thinning to eliminate the most favored species and retain and encourage the more valuable and resistant species. It will be noted that class 2 includes most of the conifers, which suffer severely if grown in association with more favored species. Unfortunately, the infested region abounds in class 1 trees either in solid stands or in more or less diluted mixtures.

[3] MOSHER, F. H. FOOD PLANTS OF THE GIPSY MOTH IN AMERICA. U. S. Dept. Agr. Bull. 250, 39 pp., illus. 1915.

FIGURE 4.—White pine growing in mixture with favored food trees, defoliated and killed by the gypsy moth.

FIGURE 5.—Oak trees defoliated by the gypsy moth.

FIGURE 6.—Hemlock growing in mixture with favored species defoliated and killed by the gypsy moth at Orange, Mass., in 1934.

CLASS 1.—*Species that are favored food for the gypsy moth larvae*

Alder, speckled
Apple
Aspen, American
Aspen, large-toothed
Balm-of-Gilead
Birch, gray
Birch, paper
Birch, red
Blueberry (*Vaccinium angustifolium*)
Boxelder
Gum, red
Hawthorn
Hazelnut
Hazelnut, beaked
Larch, American
Larch, European
Linden, American
Linden, European
Mountain-ash
Oak, black
Oak, dwarf chestnut
Oak, rock chestnut
Oak, bear
Oak, bur
Oak, pin
Oak, post
Oak, red
Oak, scarlet
Oak, shingle
Oak, swamp white
Oak, white
Poplar, Lombardy
Rose, pasture
Serviceberry
Spruce, blue[4]
Sumac, mountain
Sumac, scarlet
Sumac, staghorn
Willow, glaucous
Willow, sandbar
Willow, white
Witch-hazel

CLASS 2.—*Species that are favored food for the gypsy moth after the earlier larval stages*

Beech, American (1)[4]
Cedar, red (4)
Chestnut
Hemlock
Pine, jack
Pine, pitch
Pine, red
Pine, Scotch
Pine, western white
Pine, white
Plum, beach
Spruce, black
Spruce, Norway
Spruce, red
Spruce, white

CLASS 3.—*Species that are not favored but upon which a small proportion of the gypsy moth larvae may develop*

Barberry, European
Bayberry
Birch, black
Birch, yellow
Blueberry, low
Blueberry, tall
Butternut (4)
Cedar, southern white (4)
Cherry, sweet
Cherry, wild black
Cherry, wild red
Chokeberry
Chokecherry
Cottonwood
Cranberry, American
Elm, American
Elm, European
Elm, slippery
Gum, black
Hickory, bitternut
Hickory, mockernut
Hickory, pignut
Hickory, shagbark
Hophornbeam
Hornbeam, American
Maple, Norway
Maple, red
Maple, silver
Maple, sugar
Pear
Poplar, silver
Sassafras
Sweetfern
Sweetgale

[4] Numbers in parentheses refer to the original classification of plants that have been reclassified. Blue spruce has been subsequently added.

CLASS 4.—*Species that are unfavored food for gypsy moth larvae*

Arborvitae
Arrowwood
Arrowwood, maple-leaved
Ash, black
Ash, blue
Ash, red
Ash, white
Azalea, white and flame
Balsam, fir
Blackberry, high
Blueflag, larger
Catalpa, hardy
Cornus
Cranberry tree
Currant, red
Cypress, bald
Dangleberry
Dock, narrow
Dogwood, flowering
Elder, American
Eubotrys, swamp
Feverbush
Grape
Greenbrier
Hackberry
Hardhack, pink
Hardhack, white
Holly, American
Honeylocust
Honeysuckle, bush
Huckleberry, highbush
Inkberry
Juniper, common
Kentucky coffeetree
Lambkill (sheep laurel)
Locust, black
Maple, mountain
Maple, striped
Mountain-laurel
Mulberry, red
Mulberry, white
Osage-orange
Osier, red
Pepperbush
Persimmon
Poison-ivy
Privet
Raspberry
Sarsaparilla
Skunkcabbage
Spicebush
Sweetbrier
Sweet pepperbush
Sycamore
Tea, Appalachian
Tuliptree
Viburnum, sweet
Walnut, black
Willow, bay-leaved
Winterberry, smooth

MEANS OF SPREAD

Egg clusters of the gypsy moth deposited on trees, lumber, stone, and other products that are likely to be shipped may be carried long distances and cause new colonies of the insect to be established. The only way to prevent spread of this kind is to inspect such products and treat any clusters found on them before they are shipped.

Larvae of the gypsy moth may be carried on such moving objects as trains and automobiles. Horse-drawn vehicles and freshets may also transport them for limited distances, and egg clusters on debris may be carried by high water. The danger of such spread is dependent upon the extent of infestation along railroads, highways, and streams.

It is probable that the principal agent in the spread of the gypsy moth is the wind. The chief trend of spread of the insect, since its introduction into New England, has been to the north and northeast, which is the general direction of prevailing surface winds after the hatching season.

Since the newly hatched larvae are abundantly supplied with hairs, they are easily carried by the wind. Probably few larvae are ever blown loose from their supports by the wind. An enormous number, however, spin down from tree tops when disturbed and are intercepted by air currents; the strand of silk is broken and they are whirled away with this silk attached to their bodies. Spinning larvae normally sever the strand of silk by biting only when they come to rest upon some object; they seldom do this while hanging free. The distance that a larva may be carried aloft by currents of air depends to some

extent upon the length of silk attached to its body. Larvae have been captured on screens more than 20 miles from the nearest known infestation, and one larva has been taken on a screen attached to an airplane at a height of about 1,800 or 1,900 feet above the ground (2,000 feet above sea level). The height to which they may be carried varies from day to day and may greatly exceed 2,000 feet. Once larvae have reached such heights, they may encounter cross currents of air and be blown in the direction opposite to which surface winds are blowing.

Transportation of larvae by the wind is, however, less serious than it would appear. The farther the larvae are carried the more widely they are separated and the less chance they have of falling close enough together to establish infestations. There must be a large number of such larvae present to offset natural mortality. Millions of larvae, however, may be blown out of an infestation, fall nearby, and succeed in spreading the infestation short distances. That undoubtedly is why the infestation in New England has progressed only a few miles per year. Were it not for the tremendous natural mortality of larvae, the insect would have become established in new localities far more rapidly than it has. For this reason special efforts are made to destroy egg clusters before hatching, particularly those that are in exposed or wind-swept locations.

Wind spread takes place primarily on hot days when convection currents from the heated surface of the ground are prevalent. The appearance of cumulus clouds signifies the existence of convection currents and the days when danger of wind spread is greatest.

EFFECT OF CLIMATE

The effect of climate, in all its phases, upon the gypsy moth has never been fully investigated, and is therefore little understood. The effect of extremely low temperatures upon overwintering eggs has received more study than any other single factor. It has been determined that all egg clusters are killed when exposed to a temperature of −25° F. and that some eggs are killed at −15°.

In the field, however, temperatures fluctuate greatly within very short distances. For instance, a temperature of −25° F. at a weather station in a town or city does not necessarily mean that such a temperature is common to the entire town. For this reason it has been impossible to estimate accurately just what was happening to gypsy moth eggs in towns from which temperature records were available.

Winter temperature is an important factor in gypsy moth abundance in most of New England. In some winters the temperature does not get low enough to be fatal, but in other years mortality from this cause is heavy. In northern Maine, northern New Hampshire, and most of Vermont except the Champlain and Connecticut River Valleys, minimum winter temperatures are low enough to kill egg clusters that are not protected by snow, ice, or otherwise, and in most of these areas infestations have become established slowly and the increase of the species has been retarded.

Late frosts in the spring sometimes cause severe damage to foliage, and this usually results in heavy mortality of the small larvae. This is most likely to occur locally, but was noticeable in many sections of the infested areas during the spring of 1936. Frequently there is

also a considerable mortality of newly hatched larvae during long periods of rainy weather accompanied by low temperatures.

Evaporation is another climatic factor that is known to influence caterpillar activity. Feeding is noticeably greater when evaporation is high, the loss of water from the caterpillar's body probably acting as the stimulus. This may account for the more rapid feeding in the upper part of the crown than in the lower part. Such feeding serves to open the crown canopy, admitting more light, raising the temperature, permitting a freer circulation of air, and increasing the evaporation rate below. Thus the entire crown becomes more and more susceptible to rapid feeding. Young larvae seem to be attracted and older larvae repelled by strong light.

NATIVE ENEMIES

No insect enemies of the gypsy moth native to New England cause any noticeable reduction in its numbers. This is shown by the fact that from 1900 to 1905, when no systematic effort was made to suppress the insect, alarming injury resulted, and native insect enemies did not increase to any marked degree. The same is true of native insect-eating birds. While they undoubtedly feed to some extent on gypsy moth caterpillars, there is no record of their being able to control the insect. The "wilt," a disease that attacks and kills the caterpillars and pupae, has probably occurred in this country for many years. During some seasons it kills an enormous number of the caterpillars and is often an important factor in reducing the infestation locally. As a rule this disease is more common in heavy infestations, although many caterpillars have been killed by it when the infestation has been relatively light.

INTRODUCED PARASITES AND OTHER ENEMIES

In 1905 the State of Massachusetts, in cooperation with the Bureau of Entomology, began to introduce parasites and other natural enemies of the gypsy moth from its native home in Europe and Japan. Since that time a large quantity of parasitized material has been received, and as a result some important natural enemies have become established in this country and are assisting in the control of the pest. The enemies which have become established, and which destroy the largest number of gypsy moth caterpillars and pupae, are the beetle *Calosoma sycophanta* L.; two species of parasitic flies, *Sturmia scutellata* R. D. and *Compsilura concinnata* Meig., one of which attacks the caterpillars of the brown-tail moth as well as those of many native insects; and a small wasplike fly, *Apanteles melanoscelus* Ratz. Two tiny important parasites of gypsy moth eggs have also been established, one, *Oencyrtus kuvanae* How., having been introduced from Japan and the other, *Anastatus disparis* Ruschka, from Europe and Japan. Two other introduced parasites, *Hyposoter disparis* Vier. and *Phorocera agilis* R. D., are established in this country, but they have not increased sufficiently to be important factors in gypsy moth control.

The work of the natural enemies of the gypsy moth has greatly reduced the numbers of the insect. In some sections the reduction has been greater than in others, and their effectiveness has also varied from year to year.

Since 1911 annual examinations have been made at observation points scattered over the infested area to determine the intensity of the infestation and the percentage of eggs, larvae, and pupae killed by introduced natural enemies. These points were located in York County in southwestern Maine; in Strafford, Merrimac, Hillsboro, and Rockingham Counties in southeastern New Hampshire; and in Essex, Middlesex, Worcester, Norfolk, and Plymouth Counties in eastern Massachusetts. The results indicated a rapid building up of the natural enemies, with an increasing percentage of the eggs, larvae, and pupae being destroyed, until 1923. In the meantime the intensity of the gypsy moth infestation, which had already reached a high level in 1912, remained high until 1921, when it declined rapidly until 1924. Since then there have been fluctuations in both the intensity of the infestation and the percentage of moths destroyed, but since the natural enemies have become thoroughly established the infestation has not reached the high level attained in the earlier years in some portions of the area. To evaluate correctly the benefit derived from parasites and natural enemies, other factors, including climatic conditions, must be taken into consideration. Without doubt, however, these beneficial insects have played a useful role with other control agencies in decreasing damage by this pest.

CONTROL METHODS

GENERAL METHODS

A number of standard methods are in use for controlling the gypsy moth. They may be applied singly or in combination, depending on the tree growth, the density of infestation, and other local conditions. The essential information concerning each method is given in the following paragraphs, but each owner or operator should select the procedure that will give the best results when applied to his particular problem.

USE OF GYPSY MOTH CREOSOTE

The application of gypsy moth creosote with a brush will destroy egg clusters without removing them from the trees or objects on which they are deposited. This work can be done between the first of August and the time of hatching in the spring, which is about the first of May. Treatment can be given most satisfactorily when there is no snow on the ground.

Gypsy moth creosote is on sale in the infested area and is a low-grade coal-tar creosote which has been impregnated with sufficient coal-tar pitch to discolor the egg masses and thus indicate those that have been treated. A satisfactory grade can be bought in quantity under the following specifications:

Specific gravity	0.990–1.025 at 15.5° C.
Tar acids	10 to 15 percent.
Coal-tar hydrocarbons	80 to 85 percent.
Water, not more than	2 percent.
Flash point	70°–75° C.

No separation of naphthalene at 0° C.
Initial boiling point, 170°–180° C.; 95 percent over at 285°–295° C.

In addition, not less than 6.5 percent nor more than 8.5 percent by weight of coal-tar pitch shall be added to the creosote furnished under

this specification, in order that the finished product shall have a color suitable for the proper staining of gypsy moth egg masses. This material must remain fluid and workable at subzero temperatures.

USE OF BURLAP BANDS

Gypsy moth caterpillars usually seek shelter during hot, sunny days, and if a band of burlap is attached to a tree (fig. 7) large numbers

FIGURE 7.—Burlap band on tree showing caterpillars beneath.

of them will crawl beneath it, where they may be crushed each day. A strip of burlap about 8 inches wide is placed loosely around the tree trunk, and a piece of twine is passed around the center and tied to hold it in place. The top part of the burlap is then folded down to make a double shelter beneath it.

This method requires considerable hand labor, but is effective in many places. If brown-tail moth caterpillars are present on the

FIGURE 8.—Caterpillars on tree trunk below sticky band.

trees, burlap should not be applied until after June 15, when most of these caterpillars have pupated. Otherwise they may form their cocoons beneath it, and the workmen may be poisoned by the poisonous hairs that accumulate there.

USE OF STICKY BANDS

Bands of sticky tree-banding material, which may be obtained on the market, may be used on tree trunks (fig. 8) after the bark has been scraped so that the material can be applied evenly in a thin layer with a paddle. These bands prevent caterpillars from ascending the trees, and if proper treatment of egg clusters has reduced the number of larvae sufficiently, this is a very effective measure. Furthermore, as the caterpillars are usually massed in large numbers beneath the bands, conditions are favorable for wilt disease to develop, and the caterpillars often die in large numbers from this disease and from starvation. Every week or 10 days during the caterpillar season a comb or similar implement should be run over the band to keep the surface from hardening and to bring up fresh, sticky material from the part near the bark. This material is expensive, and considerable labor is required to prepare the trees and apply and tend the bands. In some locations, particularly where there has been a heavy deposit of egg clusters on debris on the ground or in stone walls, its use is advisable.

USE OF GYPSY MOTH TREE-BANDING MATERIAL

A black greasy substance called "gypsy moth tree-banding material" is sometimes used to prevent caterpillars from crawling up the trunks of trees. It is similar to the product known as "Raupenleim" that

has been used in German forests for many years. It has to be applied with a special gun in a thick narrow band encircling the tree trunk. At the present time it is not manufactured in this country, but information concerning its preparation and use can be supplied by the Greenfield, Mass., office of the Bureau of Entomology and Plant Quarantine.

SPRAYING

The most effective spray material is lead arsenate. To make it adhere firmly to the foliage 4 fluid ounces of fish oil or raw linseed oil should be placed in the spray tank for each pound of lead arsenate. The oil should be added after the poison is well mixed with water in the tank, and while the whole is being agitated. Agitation should be continued while the spray is being applied. The best grade of fish oil, known as "light pressed," should be used. Five pounds of lead arsenate to each 100 gallons of spray is required to kill larvae that are half grown. A slight reduction in dosage may be made for the smaller larvae. In areas where there is mixed growth it is impractical to begin the spraying until the trees that produce foliage the latest—and they are usually the oaks—are ready for treatment. Under such circumstances larvae are found in several stages of development, and use of the stronger dosage may obviate the necessity of respraying. Many investigations are being carried on to develop low-priced nonarsenical insecticides which will not be harmful to man or domestic animals. Improvements along this line would be most useful for gypsy moth spraying operations.

Warning.—Lead arsenate is a stomach poison and is toxic to animal life. It is unsafe to allow animals to graze underneath trees that have been recently sprayed. When fish oil is used as an adhesive, the spray will disfigure paint on buildings or vehicles unless it is removed with clear water before it has an opportunity to dry. Water may be provided by a low-pressure pump or from a hydrant. Fruit trees should not be sprayed with lead arsenate after the fruit is half grown, as it is difficult to remove the residue.

CLEAN-UP AND THINNING WORK

In many areas satisfactory control work cannot be attempted without the removal, and usually the burning, of infested rubbish and worthless trees. This should be done in such a way as to improve the property. Woodland areas may be thinned to advantage by removing trees that are favored as food by the gypsy moth caterpillars and encouraging the growth of better species of the less favored classes. When it is necessary to remove dead or useless wood in trees, the best practice of pruning and tree care should be employed.

EQUIPMENT

In creosoting work a brush with a round handle, which can be fitted with a cork stopper into a can containing creosote, is useful for treating egg clusters within easy reach. Those higher up can be treated with brushes that are attached at an angle to the tip of bamboo poles ranging from 8 to 18 feet in length. Axes, saws, and bark knives for marking trees are also necessary.

For applying burlap bands knives should be supplied for cutting the burlap and the twine and destroying the caterpillars. For applying sticky bands, knives or steel brushes should be used to destroy the caterpillars, and tree scrapers will be required to smooth the rough bark before the bands are applied.

The most expensive item in gypsy moth work is the spraying machinery and the equipment necessary to operate it. If orchard trees or low growth is to be treated, an orchard sprayer equipped with one or more lines of hose and with nozzles of the vermorel or bordeaux type will be satisfactory. The object of treatment is, of course, to cover all the foliage evenly with a thin deposit of spray. The higher the trees the more difficult it is to apply the material without waste. When large shade, park, or woodland trees are to be treated, high-powered spraying apparatus and use of the solid-stream type of treatment will enable the work to be done rapidly. For best results the machine should be equipped with hose 1 inch in diameter, and a nozzle pressure of 300 pounds per square inch should be maintained. The speed of the pump must be regulated according to the aperture of the nozzle. Since the quantity of liquid passing through increases with the diameter of the tip, the pump pressure has to be stepped up to furnish the 300-pound nozzle pressure necessary to break up the spray. As hose lines are lengthened or the elevation of the nozzle above the spraying machine increases, there is a loss of pressure at the nozzle due to the friction in the hose and the additional height to which the spray material must be forced. The pump should be of the triplex type, capable of delivering at least 35 gallons of liquid per minute for a short spray line. A spray tank of 300 gallons' capacity is commonly used, and the tank and suction line should be provided with strainers to keep out foreign matter, which will either injure the pump or clog the nozzle.

One-inch hose capable of withstanding a working pressure of 600 pounds is satisfactory for most park and shade-tree work, where extremely long lines of hose are not required, or where isolated areas are to be treated and the equipment has to be moved frequently. On larger and more extensive areas, or where a water supply is some distance away, a higher-powered machine and hose that will withstand a working pressure of 1,000 pounds per square inch are necessary (fig. 9). To perform a maximum amount of work the sprayer should be set at the water supply. If the machine is equipped with an auxiliary pump for drafting water to supply the tank, and the tank is divided, one section can be filled while the other is being emptied as the spraying operation proceeds, and continuous spraying will result. With equipment of this type and on areas where there are slight elevations, 4,000 to 5,000 feet of hose can be laid to reach outlying areas.

In the intensive work that is being carried on by the Bureau of Entomology and Plant Quarantine in some of the outlying areas longer hose lines are necessary, and on account of higher elevations the sprayer and the hose are required to pass a performance test of 1,500 pounds' working pressure. As much as 12,000 feet of hose has been used on work of this type. Sprayers are constructed either with a power take-off or as individual units, so that they can be transferred to a truck and moved to points where they are needed in the field. With this type of machinery and the proper diameter of tip on the

nozzle, it is possible to spray thoroughly trees from 60 to 100 feet high. By using the same type of machine under reduced pressure and attaching to the nozzle a device known as a spreader, low growth may be treated rapidly and satisfactorily.

Tests have been made during several seasons with airships, both heavier-than-air and dirigible types, to determine whether infested woodland areas could be dusted satisfactorily and economically. This method has not proved entirely satisfactory up to the present time. During the past year spraying with an autogiro has been tried, and the results have been more promising. This method has not yet been perfected sufficiently, however, to warrant its general adoption for woodland spraying, although for applying dust insecticides on certain low-growing crops it has given excellent results in some sections of the country.

METHODS TO BE APPLIED IN ORCHARDS

Of the fruit trees, apple trees are the most likely to be infested with this insect, and some injury to peach trees has been noted.

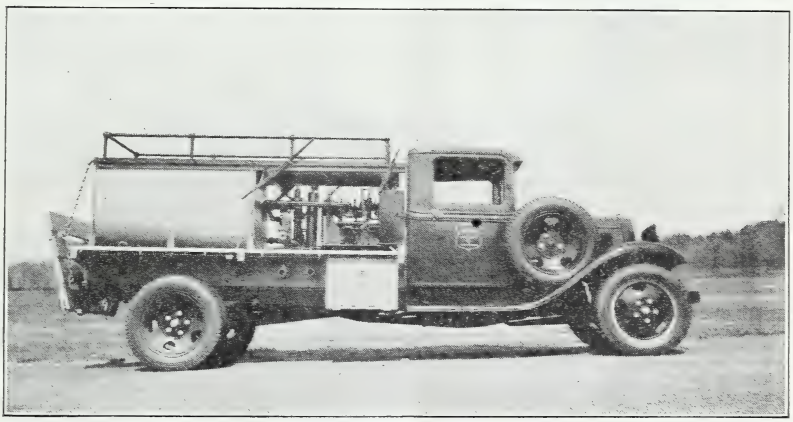

FIGURE 9.—High-power truck sprayer.

Apple orchards that are sprayed with lead arsenate for the control of other insects are protected from the gypsy moth. If systematic care or spraying of the orchard is not the practice, a program consisting of the removal of deadwood and defective trees, treatment of egg clusters, and spraying with lead arsenate and fish oil shortly after the blossoms fall should be put into operation. Orchards that are in close proximity to infested woodlands are sometimes severely damaged as a result of dispersion of small caterpillars by the wind or migration of the larger ones. This can be prevented for the most part by proper care of the surrounding woodland.

PROTECTION OF SHADE, ORNAMENTAL, AND ROADSIDE TREES

Protection of shade, ornamental, and roadside trees is vital to the communities and rural districts in which they grow, as they increase property values. In most thickly settled communities, when street planting has been done in recent years, maple, elm, and other varieties that are not favored by the gypsy moth have been planted, but

in many areas poplar, linden, willow, and, to a less extent, some of the oaks have been used. In the rural sections there has been relatively little roadside planting, and most of the shade trees are seedlings or have developed from sprouts from trees that have previously been cut. On private grounds there is a wide range of species, both native and exotic, and on such properties there are frequently many trees that are suspectible to gypsy moth attack.

To obtain information as to the species that are growing on trunk-line roads, in the summer of 1936 a hurried survey was made on one of the principal State roads from the New York State line through central Massachusetts, swinging southeast, and extending diagonally through Barnstable County to Orleans on Cape Cod. The route covered 260 miles of road, 48 miles of which was classified as city and 212 as rural. The tree growth for 50 feet on each side of the road was noted, because trees growing within these strips will eventually furnish shade for the highway. As a result of this survey 38.5 percent of the trees were rated as favored species, 27 percent were conifers and beech, which are highly favored during certain stages of the insect's development, 26.5 percent were far less favored but occasionally defoliated, and 8 percent were in the unfavored group. About 51 miles of this road was open country with no trees, and there were additional areas where trees had been cut and were being replaced by sprout growth. These sprout, or brush, areas were about 50 percent favored food. The species growing in the wooded areas adjoining these strips along the highway, and in the forest areas that were more remote, varied greatly in different localities, but it is estimated that more than half the tree growth was of favored species.

A survey of this type does not show what conditions exist in sections north or south of the road that was selected or on rural or unimproved roads. A larger percentage of favored food plants might be expected southward toward Long Island Sound, and of less favored ones in southern Vermont, New Hampshire, and Maine. The information obtained, however, indicates the necessity of protecting roadside trees from the gypsy moth. Officials in charge of tree protection could well afford to have maps indicating the growth along the streets under their control as a basis for planning for protection or replacement of the most desirable species. An endeavor should be made to remove as much of the favored growth as possible and to encourage the growth of nonfavored trees. When it is impractical to do this, treatment should be applied for the protection of the favored species. Where solid woodland adjoining the road is heavily infested with the gypsy moth, roadside trees will be denuded by migrating caterpillars. In such cases protective work should be done to prevent defoliation, and the methods that can be most economically employed should be put into practice in an area adjoining the trees along the roadway. The size of this area will depend upon the severity of the infestation.

THE WOODLAND PROBLEM

In the barrier zone and the adjoining areas, as well as in isolated infestations beyond the zone, intensive methods must be applied to curtail the infestation, not only for the benefit of the locality where it exists, but to prevent the spread of the pest beyond the known infested area. This makes necessary the use of a combination of the methods that can be most cheaply applied.

In the generally infested area it is impracticable to apply such intensive methods to large woodlands unless the property is of special esthetic value or to protect other areas that have been intensively treated. On account of the low value of most of the forest growth, some relief can be obtained by the adoption of a thinning program based on the removal of the most favored food trees in order that the food of the insect may be reduced. This work, together with the encouragement of the growth of nonfavored species, will assist in preventing damage by this insect. It can be done by the owner himself if he makes proper selection of the trees to be removed. Obviously the best silvicultural practice should be followed in such selective thinning (figs. 10 and 11). In pure or nearly pure stands of favored trees clean cutting and the planting of unfavored species is the best method of building up a resistant stand even though the cost is considerable, but there are many areas scattered through the infested territory where clean cutting is not necessary to improve the stand.

The same principles of thinning, aimed at the creation of more resistant growth, can be applied by owners even if their property is not infested, as this will reduce the opportunity for establishment of this pest. In young plantations of white pine or other conifers favored species should be removed, and if there are adjoining areas of favored growth as many of such species as possible should be removed to prevent the insect from migrating into the plantations.

RECENT CONTROL WORK IN NEW ENGLAND AND NEW YORK WOODLANDS

In both the barrier zone and the outlying infested areas intensive work is being done, most of it in woodland, to exterminate the insect and to prevent westward spread. In the zone itself such treatment has eliminated the insect in many localities in Vermont, Massachusetts, and New York. Isolated colonies are now (1937) being treated in southwestern Massachusetts and northwestern Connecticut, and in a few towns in the southern part of New York State. On Long Island and in the Borough of the Bronx in New York City the infestation has been greatly reduced. In 1936 a colony was found in Shawangunk, west of the Hudson River, and intensive treatment is being applied in this locality.

Between the barrier zone and the Connecticut River isolated colonies have been found, especially in the territory nearest the river in Vermont and over a wider area in Massachusetts and Connecticut. Work similar to that in the barrier zone is being carried on here, the number of infestations is being reduced, and infestations have been exterminated.

RECORD OF CLEAN-UP OF OUTLYING COLONIES

A few colonies of the gypsy moth have been discovered at points quite distant from the generally infested New England region, notably at Geneva, N. Y., in 1912; at Cleveland, Ohio, in 1914; at North Castle, Westchester County, N. Y., in 1914; at Rutherford, N. J., in 1914; and at Greenport, near the eastern end of Long Island, in 1921. In practically all these cases the Federal Government was assisted by the States involved in ferreting out the limits of the

FIGURE 10.—Mixed stand of hardwoods and conifers before thinning.

FIGURE 11.—Same woodland shown in figure 10 after favored food trees had been removed. Here white pine has been released from danger.

colonies and applying intensive clean-up measures, and in every case the colonies have been exterminated.

Since 1921 several other small, scattered infestations have been found on Long Island (fig. 12), and clean-up work here was undertaken by the New York Department of Conservation. Owing to its geographical location and the general trend of spread of the insect away from rather than to this island, sufficient field work should furnish ample protection from this pest.

FIGURE 12.—Locations, outside of the large New Jersey and Pennsylvania infestations and the barrier zone, where the gypsy moth has been exterminated: 1, Cleveland (Bratenahl), Ohio; 2, Loretto, Pa.; 3, Geneva, N. Y.; 4, Schenectady, N. Y.; 5, North Castle and Garrison, N. Y.; 6, Brooklyn, Roslyn, Kew Gardens, Patchogue, Shelter Island, and Greenport on Long Island, N. Y.; 7, Deal Beach, Wyckoff, South Orange, Scotch Plains, Paterson, Madison, Glen Rock, Elizabeth, and Rutherford, N. J.; 8, Henrysburg, Quebec.

EXTERMINATION PROJECT IN NEW JERSEY

In July 1920 a State inspector found the gypsy moth on a large estate near Somerville, N. J. When discovered, the infestation centered in a large plantation of blue spruce trees, several acres of which were defoliated. There were dead trees in the worst-infested portion of the plantation, with indications that they had been killed by complete defoliation (fig. 13).

The trees in this plantation had been imported from the Netherlands about 10 years before, and the infestation came with the shipment. This was prior to the enactment of the Plant Quarantine Act, and emphasizes the pressing need for precautionary measures to keep out dangerous pests.

FIGURE 13.—Blue spruce defoliated and killed by the gypsy moth.

Scouting during the fall of 1920 and the spring of 1921, financed by the State of New Jersey and the Federal Government, revealed infestations of this insect in scattered localities over an area of more than 400 square miles surrounding Somerville (fig. 14).

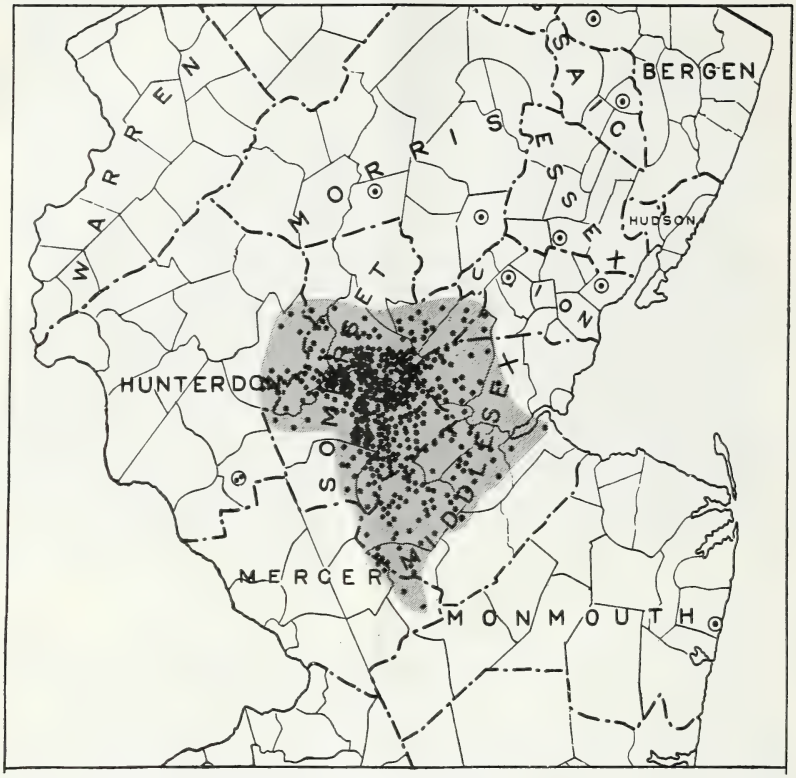

FIGURE 14.—Area in New Jersey infested by the gypsy moth in 1921. Dots indicate location of colonies within the infested area, and dots enclosed in circles indicate isolated colonies.

Previous successes in cleaning up local infestations led to the adoption of a cooperative plan to clean up this large, newly discovered infestation. State and Federal funds were appropriated, and the work was organized under the direction of the field office for gypsy moth control of the Bureau of Entomology. When the limits of infestation had been determined, the area was placed under State quarantine, which required as a condition of movement the certification of freedom from infestation of all products likely to carry any stage of the gypsy moth. Thorough inspection, which permitted certification, was made in cooperation with the Federal Government and by Federal inspectors. The area under regulation has been gradually reduced as a result of the clean-up work, and in 1932 Federal operations were stopped and all inspection requirements were withdrawn.

As soon as active work was under way in New Jersey, it was learned that trees had been shipped from the estate on which the insect was first discovered, and that the danger of its establishment in many

localities was very great. Fortunately, a record of all these shipments was available. It was found that 261 shipments had been sent to the District of Columbia and the following States: Connecticut, Delaware, Florida, Illinois, Indiana, Kentucky, Maryland, Minnesota, Missouri, New York, North Carolina, Ohio, Pennsylvania, Virginia, and Wisconsin. These shipments were traced and the planted stock was inspected by State or Federal officials. In addition, 318 shipments that had been distributed in New Jersey were followed up in the same way.

As a result of this work small infestations were found at Loretto, Pa.; Garrison, Roslyn, and Kew Gardens, N. Y.; and Deal Beach, Wyckoff, South Orange, Scotch Plains, Paterson, Madison, Glen Rock, and Elizabeth, N. J. These small infestations were cleaned up the following year, and repeated scouting has failed to indicate the presence of the pest.

In the meantime the center of the infested area was receiving intensive treatment, including spraying, and an enormous number of egg clusters were destroyed. It is significant that no trees in New Jersey have suffered from gypsy moth feeding since that time. During the next 4 years scouting and clean-up operations were continued throughout the known infested area, particular attention being paid to extensive woodlands north of Somerville, known as the Watchung Ridge. These areas were heavily wooded and were difficult and expensive to work.

Since 1925 the gypsy moth has been steadily reduced in numbers. The scouting and clean-up work covered over 2,369 square miles, although the towns in which colonies were found were in an area of 924 square miles. Federal operations were discontinued in 1932, as no infestations had been discovered since 1929. Since 1932 the State force has been making inspections in many localities and has uncovered a few small infestations along the northern border of the old infested area. These have been treated by the Federal Government in cooperation with the State. Although a large amount of intensive work has been done, no infestation has been found during the past 2 years.

Table 1 shows the number of townships in the barrier zone, New York, and New Jersey where the gypsy moth has been eradicated and the number of infestations that have been cleaned up. It indicates the protection that has been afforded to other sections of the United States.

TABLE 1.—*Townships in the barrier zone, New York, and New Jersey, where gypsy moth infestations have been eradicated, with the number of infestations cleaned up, fiscal years 1920–1935*

State	Infested townships	Infestations exterminated	State	Infested townships	Infestations exterminated
In barrier zone:	*Number*	*Number*	South and west of barrier zone:	*Number*	*Number*
Connecticut	20	92	New Jersey	38	878
Massachusetts	27	362	New York	17	567
New York	24	75			
Vermont	18	78	Total	55	1,445
Total	89	607	Grand total	144	2,052

EXTERMINATION PROJECT IN PENNSYLVANIA

Late in July 1932 a serious infestation was discovered near Pittston, Luzerne County, Pa., through the location of male moths by a biology student. A survey was made and scattered infestations were found over a wide area. An eradication program was adopted under the supervision of the officials of the Federal Bureau of Ento-

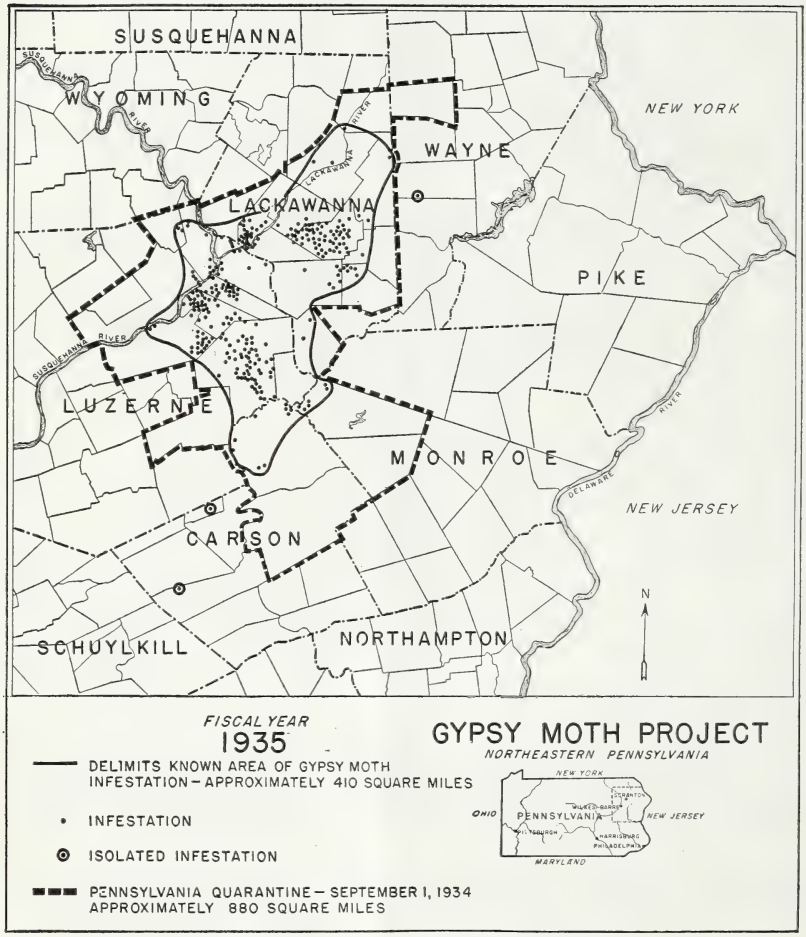

FIGURE 15.—Gypsy moth infestation in northeastern Pennsylvania in 1935.

mology in cooperation with the Pennsylvania Department of Agriculture and Department of Forests and Waters, and an office was established in Wilkes-Barre. From the fall of 1932 to the spring of 1933 over 1,200 acres of tree growth were thinned and cleared of brush and worthless and dead trees in the worst infested portion of the area. During the same period about 2 million egg clusters were destroyed by creosoting. In the summer of 1933, 3,200 acres of woodland and thousands of trees in residential sections and open country were

sprayed. A larger area was thinned and cleaned during the fall and winter.

The work has been intensified and expanded since that time, and there has been a marked decrease in the number of egg clusters treated each year. Some new infested points have been found, and they have been promptly treated. No defoliation has been noted since the first summer. The infested areas and some of the surrounding townships have been placed under a State quarantine, and movement of materials likely to carry the insect is not permitted until they have been inspected and certified by officials from the Wilkes-Barre office.

The area infested in 1935 is shown in figure 15. The present infested area aggregates 680 square miles, and additional areas surrounding it totaling 320 square miles are covered by the quarantine and inspection regulations. This includes Coolbaugh and Foster, which were added in 1936.

Substantial progress has been made on this project in Pennsylvania, and excellent cooperation has been received from the State. The territory is located in the heart of the anthracite district, and much of the country is wooded and mountainous, and therefore difficult to work. Part of this area is in the valley of the Susquehanna and Lackawanna Rivers, and some infestations have been found in the Pocono Mountain range. This infestation is located the farthest west of any in the United States, and the importance of reducing the abundance of the insect and bringing about its final extermination cannot be overestimated. If the work is not continued aggressively, the insect might spread rapidly to surrounding territory and to other States where it is not now known to exist.

THE BROWN-TAIL MOTH

HISTORY OF THE PEST IN THE UNITED STATES

The brown-tail moth (*Nygmia phaeorrhoea* Don.) was first found in the United States in Somerville, Mass., in the summer of 1897, and was undoubtedly introduced several seasons previous to that time on imported nursery stock. The insect increased enormously, and as the caterpillars were fond of the foliage of fruit and ornamental trees and shrubs, they became an unbearable nuisance, particularly in residential sections. Not only was complete defoliation common early in the summer, but as the hairs from the caterpillars caused serious poisoning to human beings the presence of this pest became a veritable scourge in densely populated areas. The insect extended its range very rapidly, because the moths of both sexes fly freely. This species occurs in many parts of Europe and is frequently very injurious.

The State of Massachusetts applied suppressive measures from the winter of 1897 until February 1900, when it discontinued the work along with that of the gypsy moth. By 1905 the brown-tail moth was extremely abundant in eastern Massachusetts. It was also present in enormous numbers in Rhode Island, southern New Hampshire, and southwestern Maine. Not only did fruit and shade trees suffer defoliation, but large areas of oak woodland, particularly sprout growth, were completely defoliated.

The insect continued to spread until 1915, when most of the area east of the Connecticut River, with the exception of a portion of northern New Hampshire and Maine, was heavily infested. Some infestation also existed in Vermont and west of the Connecticut River

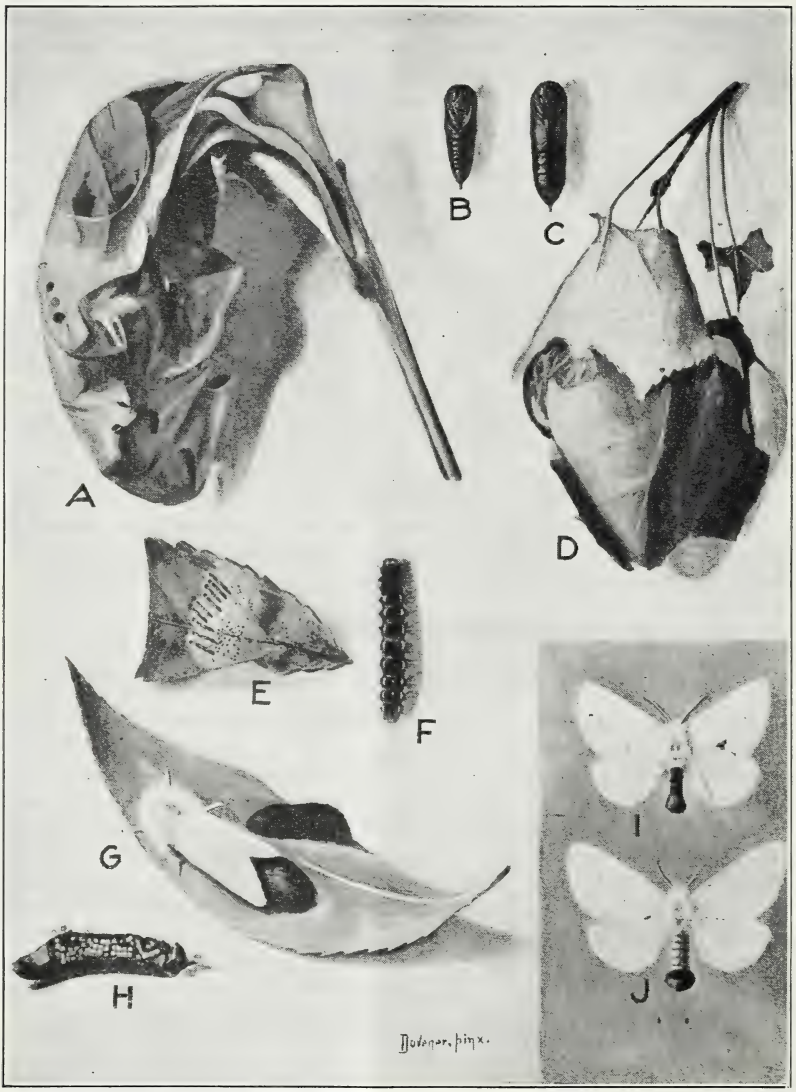

FIGURE 16.—Life stages of the brown-tail moth: *A*, Winter nest; *B*, male pupa; *C*, female pupa; *D*, cocoon in leaves; *E*, young caterpillars on leaf; *F*, full-grown caterpillar; *G*, female depositing eggs on a leaf, and egg mass also on leaf; *H*, egg mass removed from leaf and with some of the eggs exposed; *I*, male moth; *J*, female moth. All about three-fourths natural size.

in Massachusetts and Connecticut. Suppressive work carried on by the States and the Federal Government kept the residential sections fairly free from this pest.

The area now infested by the brown-tail moth is shown in figure 1, and is much less extensive than formerly. Low winter temperatures,

particularly in the northern part of the territory, coupled with the work of natural enemies and disease and the continuous repressive measures used in the residential sections, have caused a remarkable decrease in the abundance of this pest. The insect has been found in Nova Scotia and New Brunswick, but has not been reported from there in excessive numbers for several years.

This pest can easily be shipped on woody plants, but general spread in this manner has been prevented by the strict enforcement of inspection and quarantine regulations.

LIFE HISTORY

The different stages in the development of the brown-tail moth are shown in figure 16.

THE EGGS

The female moth deposits a small cluster of from 200 to 400 eggs on the underside of a leaf. They are usually laid in July, and are covered with brown hairs from the body of the female. Hatching begins about August 15.

THE LARVAE

The newly hatched larvae, or caterpillars, feed on the epidermis of the leaf. After molting once or twice they construct a winter web. This is made by drawing together several terminal leaves and fastening them with silk which they secrete. The larvae from one or more egg clusters live and feed in common, and as cold weather approaches they retire to the web, in which they remain during the winter. In the spring, as soon as the buds begin to develop, the larvae leave the web and feed upon the bud scales and small leaflets. As they increase in size they consume most of the foliage. They become full grown late in June.

The full-grown larva, which is hairy, is about 1½ inches long. The head is light brown. The body is dark brown to almost black, with a broken white line on each side and two conspicuous reddish spots on the dorsum near the posterior end.

THE PUPAE

After the caterpillars have finished feeding, they spin loose silken cocoons in which to pupate. These cocoons may be constructed separately, or large numbers may be spun in a single mass. Sometimes leaves are drawn together as shelters; in other cases the cocoons are attached to trees or other objects. About 2 weeks is spent in the pupal stage.

THE ADULTS

Emergence of the moths usually begins the first week in July. The adult is pure white, except for the tip of the abdomen, which is covered with brown hairs. The body of the female is much larger than that of the male. These moths are attracted to strong light, and as they fly at night they are often seen around electric lights in cities and towns during the first half of July.

FOOD PLANTS

The caterpillars of the brown-tail moth feed on the leaves of apple, pear, cherry, oak, and willow, and they are sometimes found in considerable numbers on other common deciduous trees and shrubs.

They never attack conifers and are seldom found on hickory, ash, or other trees.

Oak foliage is one of the favored foods of the brown-tail moth caterpillars in Europe and was severely injured in New England for a number of years after this insect became established there. It has not suffered in this way in recent years except in Maine and New Hampshire in 1933, when the insect was unusually abundant, and then some webs were found on oak trees and the caterpillars caused considerable defoliation locally.

INJURY CAUSED BY THE BROWN-TAIL MOTH

The principal injury caused by the brown-tail moth is due to the feeding of the larvae in the spring. The caterpillars are often numer-

FIGURE 17.—Apple trees defoliated by the brown-tail moth. Note the hibernating webs on the twigs.

ous enough to devour the leaves as fast as the trees are able to develop them. As the webs are made on the terminals, the growth of the trees is often severely checked. In severe infestations trees may be completely stripped (fig. 17), but as the larvae grow rapidly during the first part of June there is usually an opportunity for the trees to produce new leaves before midsummer. The larvae hatch in August and frequently skeletonize the leaves, but this does not damage the trees seriously, as the growing period for the season is nearly over.

The bodies of the caterpillars are provided with poisonous hairs. A microscopic examination of these hairs shows that the edges are barbed in such a way as to cause intense irritation when they come in contact with the human skin. They are also hollow and contain a substance which acts on the blood corpuscles. Poisoning and irritation caused by this insect are accompanied by external swelling, and is known as the brown-tail rash. Persons differ in their susceptibility to this poison, but many cases are reported each year in the infested area. Many camps and summer cottages cannot be occupied with

any comfort during the early summer if the caterpillars are abundant. If clothing is hung on the line near badly infested trees, the hairs frequently find lodgment and are brought into the houses, with consequent poisoning of the inhabitants.

NATIVE ENEMIES

One of the important native enemies of the brown-tail moth is a fungus disease (*Entomophthora aulicae* Reich.) which attacks the caterpillars. It was first reported in this country by Roland Thaxter in 1888. Like all diseases of this nature, the benefit derived from it is regulated largely by weather conditions. This fungus sometimes works to a slight degree on the small caterpillars in the fall, and is found occasionally in the winter webs. As a rule, however, the greatest mortality of caterpillars takes place in the spring, when they are nearly full grown, and the pupae may, under the most favorable conditions, be almost completely exterminated.

Native parasites and predacious insects have done little to check the increase of the brown-tail moth.

INTRODUCED PARASITES AND OTHER ENEMIES

Compsilura concinnata Meig., one of the species introduced as an enemy of the gypsy moth, attacks the caterpillars of the brown-tail moth freely, while two others, *Apanteles lacteicolor* Vier. and *Sturmia nidicola* Towns., that were introduced from Europe at about the same time are also important enemies of the insect. Other imported enemies, *Carcelia laxifrons* Vill., *Meteorus versicolor* Wesm., and *Eupteromalus nidulans* Foerst., that have become established help to reduce the numbers of the moth but are not usually of great importance.

EFFECT OF LOW TEMPERATURES

Extremely low temperatures in the winter often prove fatal to a large proportion of the small caterpillars in the webs. When unprotected by snow or other covering, they are usually killed by temperatures below —25° F.

METHODS OF CONTROL

The brown-tail moth can be controlled by cutting off the winter webs and burning them before the caterpillars begin to emerge in April. These webs should be destroyed by fire, for if they are simply cut from the trees and left on the ground, the caterpillars will emerge and no benefit will result from the work that has been done.

In orchards it is sometimes inadvisable to cut the winter webs, for where an infestation is heavy the cutting is likely to leave poorly shaped trees. Spraying in the spring is not a satisfactory remedy unless the infestation is very light, because large numbers of caterpillars do not allow the tree to put out sufficient foliage to hold the spray material.

An effective method in orchards is to spray the trees before the middle of August, using 3 pounds of powdered lead arsenate to 100 gallons of water. Before doing so the orchardist should determine to what extent the trees are infested with egg masses of the brown-tail moth. In spraying fruit trees, particularly early fall varieties,

caution should be used to avoid excessive spray residues. The foliage should be treated, particularly the terminal shoots, and care should be taken not to cover the fruit. Late fall or winter varieties of fruit may be sprayed with lead arsenate in August, and although an occasional spot may be found on the fruit at the time of picking, no injury will result from it. Where only a few choice fruit trees are sprayed, it is practicable to wipe the fruit before packing it for sale.

The damage caused by the brown-tail moth is ordinarily not so severe as that due to the gypsy moth, because the brown-tail moth does not have so wide a range of food plants and, since most of the feeding is done early in the season, the trees have an opportunity to recover before midsummer. In the territory where both insects exist the caterpillars of the gypsy moth supplement the feeding done by those of the brown-tail moth, and the injury is therefore greatly increased.

Thorough destruction of the webs in residential sections and in orchards has materially reduced the infestation in such places. Elimination of worthless apple and wild cherry trees would help greatly in reducing the pest.

RECENT CONTROL EFFORTS

In the winter of 1933–34 an extensive Civil Works Administration brown-tail-moth project was carried on, under the direction of the Bureau of Entomology in cooperation with the New England States, in which almost 24 million webs were cut and burned. Although the insect was much less abundant the following summer, during the winter of 1934–35 almost 2 million webs were cut and destroyed by State officials using local or State funds. The following winter a Works Progress Administration project was conducted by the Bureau in cooperation with the States, and more than 4½ million webs were destroyed. The work was continued during the winter of 1936–37, and up to the end of March more than 2¾ million webs had been cut and destroyed.

The destruction of such large numbers of winter webs has resulted in a decided decrease in infestation over much of the infested area. Prior to the C. W. A. work heavy defoliation was common in many parts of this area. During the past summer little defoliation was found. Towns have been found in all the infested States where no infestation could be located, and it should be possible to reduce the affected territory materially if the work is continued.

ORGANIZATION AND STATUS OF WORK AGAINST THE GYPSY MOTH AND THE BROWN-TAIL MOTH

Each State infested with the gypsy moth and the brown-tail moth is carrying on control work, and many of the towns and cities are similarly engaged. The Dominion of Canada and several of the Provinces have also taken up control and eradication work.

MAINE

In Maine the work is in charge of the commissioner of agriculture, who has authority to appoint assistants to supervise the operations. In the southwestern part of the State the gypsy moth infestation is

general and, in places, severe; the northern part of the insect's range is only lightly infested. The severity of infestation increased in 1932 and 1933, and many heavily infested sections have been found since that time. Several small infestations were found in the eastern part of Washington County in 1936. The brown-tail moth was very abundant in the southwestern part of Maine from 1931 to 1933, but the wholesale cutting of the webs has greatly reduced the infestation. Over 12,000 square miles in the State are infested with the gypsy moth, and about 7,000 with the brown-tail moth. The latter has been spreading to new territory since 1931.

NEW HAMPSHIRE

The moth work in New Hampshire is in charge of the State entomologist. Over 8,000 square miles are infested with the gypsy moth and about 5,000 square miles with the brown-tail moth. Most of the territory from Lake Winnipesaukee south to the Massachusetts line has suffered severe and repeated defoliation from the gypsy moth. The territory directly north and northeast of the lake has also had considerable defoliation. The same areas were heavily infested with the brown-tail moth from 1931 to 1933. Since that time the infestation has been greatly reduced by control work, and also, in some sections, by winter mortality of the larvae.

VERMONT

In Vermont the moth work is in charge of the commissioner of agriculture, who appoints an entomologist to carry on the field work. After intensive scouting for the gypsy moth in the winter of 1933–34, the area under quarantine was reduced from about 6,000 to 4,500 square miles. The heaviest infestations are located along the Connecticut River. Only a few brown-tail moth infestations have been found in Vermont in recent years. A survey along the eastern border of the State in 1933 and 1934 indicated a number of scattered infestations, and this area was placed under quarantine. As a result of work done since that time no infestation by this insect has been found during the last 2 years.

MASSACHUSETTS

The commissioner of conservation has charge of the moth work in Massachusetts. Each infested town is required by law to select a local superintendent, whose appointment must be approved by the commissioner. Owners are required by law to keep their property free from these pests, but cannot be compelled to expend for this purpose more than $5 per year on each $1,000 assessed valuation. Towns and cities must provide for proper treatment of the street trees and those in parks and on public grounds. After the amounts fixed by law are expended, financial aid may be supplied by the State. The gypsy moth at present (1937) occurs in every town in the State east of Berkshire County. It has increased in abundance over much of the infested area during the last 3 years, especially in the towns directly east of the Connecticut River. The area infested by the brown-tail moth is a little over 4,500 square miles.

RHODE ISLAND

In Rhode Island the commissioner of agriculture has charge of the moth work, which is done under the supervision of the State entomologist. The gypsy moth occurs in all towns in the State. Since 1931 the infestation has increased rapidly, and in 1934 much defoliation was noted. The conditions approximate those which the State of Massachusetts has encountered for many years. No brown-tail moth infestation had been found for a number of years prior to 1936, when a few webs were found in two towns in the eastern part of the State.

CONNECTICUT

In Connecticut the work is in charge of the State entomologist. The brown-tail moth has not been found in this State for several years. The area infested by the gypsy moth is now about 3,000 square miles. During the past 3 years the infestation has increased noticeably in some localities in the eastern part of the State.

NEW YORK

In New York State the work is supervised by the Department of Conservation, which is cooperating with the Federal Bureau of Entomology and Plant Quarantine in the New York section of the barrier zone. A few scattered infestations in eastern New York and on Long Island, including New York City, and a newly discovered infestation at Shawangunk, west of the barrier zone, are being treated by the State. During the past 2 years a special survey of the entire State has been made, but no additional infestations have been found.

NEW JERSEY

In New Jersey the State work is under the control of the State Department of Agriculture. The funds appropriated have been used in conjunction with Federal funds, and the work is supervised by the Bureau of Entomology and Plant Quarantine. No infestation has been found for 2 years.

PENNSYLVANIA

In Pennsylvania the work is carried on under the direct supervision of the Bureau of Entomology and Plant Quarantine of the United States Department of Agriculture, with the cooperation of the Pennsylvania Department of Agriculture and Department of Forests and Waters. Progress has been made in the eradication work conducted in this State.

DOMINION OF CANADA

Scouting for the gypsy moth and the brown-tail moth in Canada is conducted by the Division of Foreign Pests Suppression of the office of the Government entomologist. Cooperation with the provincial governments of New Brunswick, Nova Scotia, and Quebec has been maintained. The gypsy moth colony found at Henrysburg, Quebec, has been exterminated through the efforts of the Dominion and provincial officials. Late in 1936 a few gypsy moth egg clusters were found in and around St. Stephen, New Brunswick, and extensive scouting and clean-up work has been done.

UNITED STATES DEPARTMENT OF AGRICULTURE

The gypsy moth project has been conducted by the Bureau of Entomology for many years. On July 1, 1928, the quarantine and control work was transferred to the Plant Quarantine and Control Administration, which later became the Bureau of Plant Quarantine, and the research work was assigned to the Division of Forest Insects of the Bureau of Entomology. On January 1, 1934, the quarantine work was transferred to another section of the Bureau, and on July 1, 1934, the two bureaus became the Bureau of Entomology and Plant Quarantine.

For a number of years it was believed to be impossible to restrict the spread of the brown-tail moth on account of the heavy migration of the adults. Owing, however, to the effectiveness of parasites introduced by the Bureau, to winter conditions unfavorable to the insect, and in some sections to the effectiveness of a fungus disease that attacks the caterpillars, in addition to a large amount of hand suppression work, not only was spread prevented but marked reduction in the infested area recorded.

A large amount of experimental work has been done to devise better methods of controlling these insects. Natural enemies have been introduced from Europe, northern Africa, and Japan and colonized throughout most of the infested area. Specialists have spent considerable time studying the insects in their native homes and collecting parasites for shipment to this country.

The entire area known to be infested by either of these insects is under quarantine, and shipments of nursery stock, lumber, cordwood, and other forest products, including Christmas trees and greenery and stone and quarry products, are not permitted to leave the territory unless they are inspected and accompanied by a certificate stating that they are free from infestation.

The results of the work in the barrier zone in preventing spread and the cleaning up of isolated infestations have justified the efforts expended and have protected the United States at large from infestations and resultant damage from these pests.

COOPERATIVE WORK

Since the gypsy moth and brown-tail moth work was begun by the Bureau of Entomology, more or less work has been done in cooperation with the States concerned. The general plan of field work in New England is for the States to manage the clean-up east of the barrier zone while the Federal forces work in the zone and cooperate in making the entire work effective.

In New York the work in the barrier zone is handled in cooperation with the State authorities.

In New Jersey and Pennsylvania close cooperation has been maintained with the State departments.

During the past 3 years the work has been extended and intensified through cooperation with the N. R. A., W. P. A., and C. C. C., and recently cooperation has been established with the Northeastern Forest Experiment Station of the Forest Service for the purpose of utilizing the latest silvicultural methods in connection with the control work in forests.

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